

## LOW-TEMPERATURE, LONG-TIME HEATING OF BOVINE MUSCLE

### 1. Changes in Tenderness, Water-Binding Capacity, pH and Amount of Water-Soluble Components

**SUMMARY**—Relationships between the tenderness of very slowly cooked meat and its water-holding capacity, pH and the amount of water-soluble components were studied. Beef muscle portions from the longissimus, semitendinosus and rectus femoris muscles were heated under fixed temperature programs with samples from each analyzed at 1-hr intervals between the 3rd and the 10th hr of heating. Weight losses after holding at the final temperature to the 24th hr were determined. During the first 4 hr of heating there were only minor changes in tenderness. The major decrease in shear values occurred between the 4th and 6th hr, when the meat was warming from 50–60°C. The weight losses increased rather linearly to the 7th hr and remained constant for the longissimus and the semitendinosus muscle. The pH values gradually increased during heating. During the first 3 hr of heating, up to 45°C, there was only a slight decrease in the amount of the water-soluble fraction. During the following 3 hr, from 45 to 58°C, the water-soluble fraction decreased more rapidly and the decrease was only slight during a following 4-hr holding period. After 6 hr of heating to 60°C there were still uncoagulated water-soluble proteins. These studies indicate that the final temperature of meat has great influence on tenderness and weight loss. The significance of the shrinkage of collagen in long-time, low-temperature cooking is considered.

### INTRODUCTION

THE TENDERIZING effect of long-time, low-temperature cooking has been widely studied since Cover (1937) found that well-done roasts were more tender when cooked at 124 than at 225°C. Bramblett et al. (1959; 1964) found that muscles cooked at 68°C were more tender and had slightly better appearance and flavor than those cooked at 93°C, although they were less juicy. These workers concluded that the length of holding between 57 and 60°C was closely related to increased tenderness. Marshall et al. (1960) found that during low-temperature roasting, evaporation losses increased with the internal temperature of the meat, drip losses increased with increasing oven temperature and with increasing internal temperature and that the total losses were greater in the lowest-temperature oven. Schoman (1960) found that juice losses and power consumption could be reduced by roasting at 121 instead of 149°C in a moisture-tight forced-convection oven. These results indicate that low-temperature cooking affects the water-binding capacity of the meat.

Dymit (1961) introduced the "delayed service" method of meat cookery. He browned beef ribs for 1.5 hr at 178°C, then held them for 3–48 hr at 60°C. Flavor, tenderness and juiciness improved during the first 24 hr and remained constant during the next 24 hr at 60°C. Only 15% shrinkage was observed. Gaines

et al. (1966) used a much higher browning temperature, 218°C, and the internal temperature of the roasts never reached the collagen melting point and they were more raw and less tender than the control samples. Funk et al. (1966) also used a higher browning temperature than Dymit, and also reported a decreased quality using the delayed service method. It would appear that the more severe browning used by Gaines et al. and Funk et al. impeded subsequent heat penetration at the lower temperatures, probably due to a severely coagulated surface layer. Korschgen et al. (1963) roasted large cuts of beef to an internal temperature of 43°C in a 149°C oven. The meat was then cooled and sliced. They then broiled slices for 3 min on each side on a 204°C grill. This procedure resulted in good tenderness even of the visible connective tissue.

It is evident from these studies that the rate of heating can affect various properties of the meat associated with tenderness. Yet the extent and nature of the changes are not clear, due primarily to the use of different heating rates by different workers. In the present study, well-defined conditions of low-temperature cooking were followed. At regular intervals, the water-holding capacity, pH, amount of water-soluble components and tenderness were measured. The objective was to detect relationships between tenderness and these parameters.

### EXPERIMENTAL

#### Raw materials

Longissimus, rectus femoris and semitendinosus muscles from both sides of 3 Hereford steer carcasses were used. The carcasses graded

either Prime or Choice and had Moderately Abundant or Slightly Abundant marbling. After aging 5–7 days at  $0 \pm 1^\circ\text{C}$ , the muscles were separated and trimmed of fat and epimysium. They were cut into 2.5-cm-thick slices weighing 100–130 g and sealed under vacuum in Cryovac bags. They were then returned to  $0^\circ\text{C}$  until each muscle had been aged for 2 wk from slaughter.

#### Heating rates

A preliminary experiment showed that the center temperature of a 15.7-kg steamship round roast increased about  $0.1^\circ\text{C}/\text{min}$  when cooked at  $121^\circ\text{C}$  in an institutional gas-heated oven. Therefore, the experimental samples were cooked in the sealed plastic bags by submerging in a  $30^\circ\text{C}$  water bath and increasing the bath temperature  $0.1^\circ\text{C}/\text{min}$  until the bath reached  $60^\circ\text{C}$ . This temperature was maintained until the total cooking time was 10 hr. From the 3rd to the 10th hr samples were removed from the water bath every hour. In addition, samples were removed from the water bath at 36 and  $44^\circ\text{C}$  and heated in 2 other baths at 37 and  $45^\circ\text{C}$  until total cooking periods of 6 and 10 hr were reached. One control sample from each muscle was at first tempered 1 hr at  $30^\circ\text{C}$  in a water bath, then heated up to  $80^\circ\text{C}$  in 1 hr, and kept at this temperature for 1 hr. This is similar to the schedule used by Marsh et al. (1966). The approximate meat temperature-time curves and the sampling points are shown in Figure 1.

#### Meat evaluation

Tenderness was measured as shear value in pounds using a Warner-Bratzler apparatus. Test cores were 2.5 cm in diameter, and an attempt was made to keep the axis of the core parallel

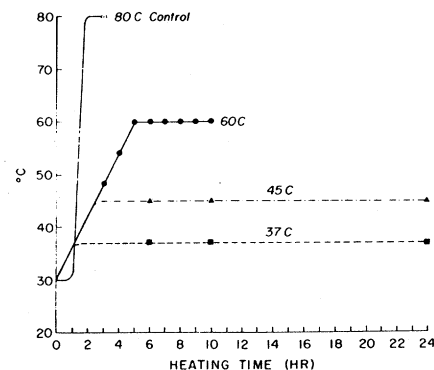


Fig. 1.—Approximate heating curves for muscles cooked at different rates. The dots represent times and temperatures when samples were withdrawn for analysis.

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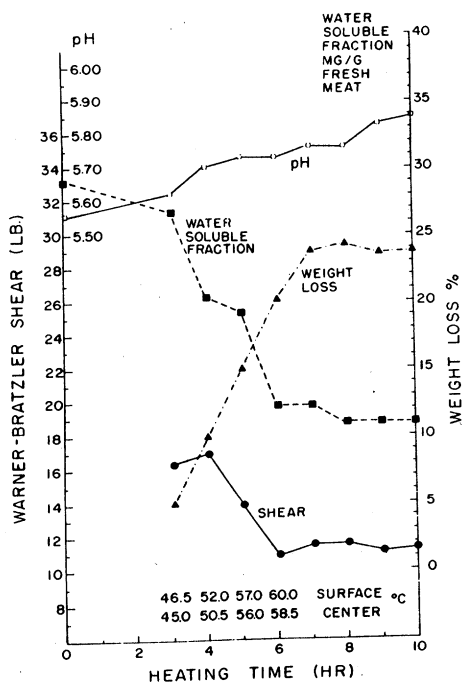


Fig. 2.—Shear value readings, weight loss, pH and amount of freeze-dried water-soluble fraction in longissimus muscle heated at 0.1°C/min to 60°C and held for 10 hr total heating time.

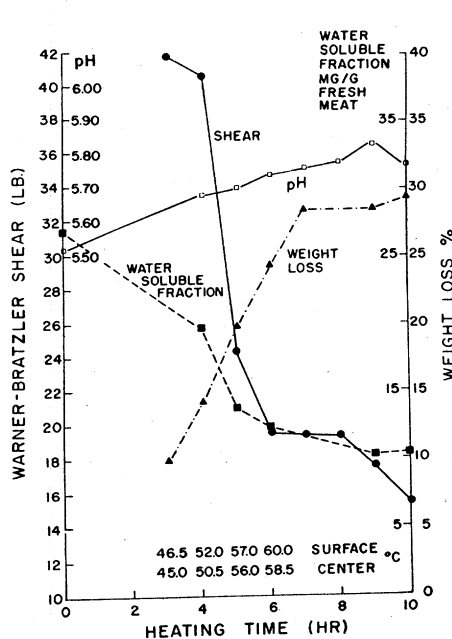


Fig. 3.—Shear value readings, weight loss, pH and amount of freeze-dried water-soluble fraction in semitendinosus muscle heated at 0.1°C/min to 60°C and held for 10 hr total heating time.

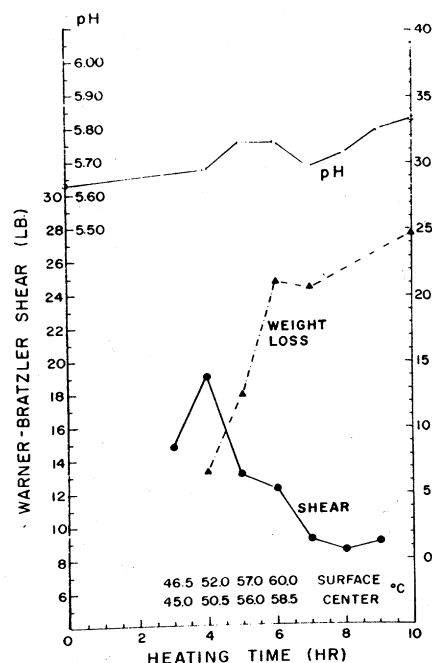


Fig. 4.—Shear value readings, weight loss and pH in rectus femoris muscle heated at 0.1°C/min to 60°C and held for 10 hr total heating time.

to the muscle fiber. 3 such cores were taken at each sampling point and each core was first sheared into halves and these were sheared again, thus giving 9 shear values for each muscle sample.

Water accounts for the major portion of the weight loss during meat cooking, especially with low-fat cuts. Therefore, the weight loss reflects the water-binding ability of the meat proteins. The samples were weighed before and after heating and the weight loss reported as percent of original weight.

The water-soluble material, largely protein, was extracted according to the scheme suggested by Maier et al. (1966). 15 g of meat were cut into strips with scissors and 60 ml distilled water added. The mixture was homogenized for 30 sec in a Waring Blender. The pH of the homogenate was determined. The homogenate was then centrifuged 30 min at 2,000 × g at 0 ± 1°C. The supernatant was filtered and freeze dried. The dry matter was weighed and is reported herein as milligrams per gram uncooked meat.

## RESULTS & DISCUSSION

### Relationships between factors studied

Values for tenderness, weight loss, pH and water-soluble fraction observed throughout cooking the longissimus are shown in Figure 2. Similar values for the semitendinosus muscle and rectus femoris are shown in Figures 3 and 4, respectively. Values shown are means of measurements made on 3 different samples of each muscle, except for the amount of water-soluble material, which is the mean of 2 determinations. These values appear in Figure 4. The water-soluble material was not determined for rectus femoris.

During the first 4 hr of heating there were only minor changes in the tenderness. Both the longissimus and rectus femoris appeared to increase slightly in shear value between the 3rd and 4th hr, although the differences were within the standard deviations of the observations. Both muscles were significantly more tender (lower shear values) than the semitendinosus. The major decrease in shear values occurred between the 4th and 6th hr, when the meat was warming from 50 to 60°C. The rectus femoris continued to show decreasing shear values to the 8th hr, but the longissimus did not show further changes after the 6th hr. Shear values of the semitendinosus muscle remained constant between the 6th and 8th hr, then decreased further during the remainder of the heating schedule. The final shear values of the semitendinosus muscle were close to values obtained for the 2 other muscles after 3 hr of heating.

Weight loss upon cooking is a usable, if imprecise, measure of the water-holding capacity of meat (Hamm, 1960). Each muscle showed a slightly different pattern in weight loss during cooking. The weight losses increased rather linearly to the 7th hr, then remained constant for the longissimus and the semitendinosus muscles. After 6 hr, when the temperature of the meat had just reached 60°C, the weight loss of the rectus femoris held constant for 1 hr, then increased more gradually to the end of cooking. Between the 4th and 6th hr, rates of weight loss were 5.3, 7.2

and 4.4%/hr for the longissimus, semitendinosus and rectus femoris muscles, respectively.

The pH values gradually increased during heating, although there were fluctuations in the rate of rise. These fluctuations may have been due to pH variations between different parts of the same muscle (Lawrie, 1966) as well as to the use of samples from different animals. The largest fluctuations and slightly higher average pH of the unheated muscle were found in the rectus femoris. Since there were also fluctuations in tenderness and weight loss of this muscle during heating all these factors may reflect some special properties of its proteins.

During the first 3 hr of heating, up to 45°C internal temperature, there was only a slight decrease in the amount of the water-soluble fraction. During the following 3 hr, 45.0–58.5°C internal temperature, the water-soluble fraction decreased more rapidly. The decrease was only slight during the following 4-hr holding period. The final values were higher than for the control samples showing that there were still uncoagulated water-soluble proteins in the meat. The water-soluble fraction includes both proteins and salts. It is estimated from data presented by Lawrie (1966) that about 2/3 of the water-soluble material are sarcoplasmic proteins. As these proteins coagulate, they can no longer be extracted. It follows that changes due to heating represent a measure of protein

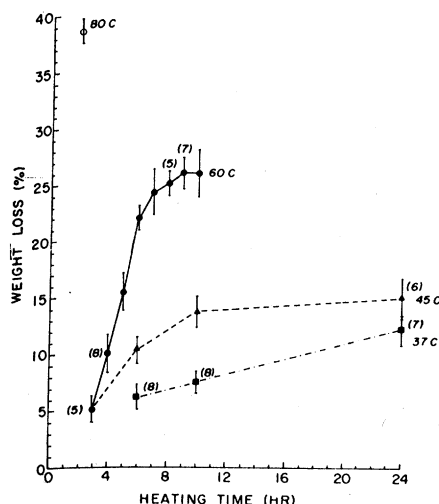


Fig. 5.—Effect of heating temperature on the average weight loss of 3 muscles (longissimus, semitendinosus and rectus femoris) from 3 Hereford steers. The data represent means and standard deviations of 9 measurements, except when the number of measurements is indicated in parentheses.

coagulation. The total water-soluble fraction of the unheated longissimus was .91%, considerably lower than the value obtained from Lawrie (1966). One reason for this may be differences in extraction methods, but another reason is probably the influence of aging and freeze-drying of the samples (Fujimaki et al., 1964). Kronman et al. (1960) reported  $2.51 \pm 0.17\%$  water-soluble protein in aged muscle.

After 6 hr of heating, the samples had reached approximately 60°C, and represented the conditions in rare meat. At this temperature the largest decrease in shear value had just been completed. Authorities agree that the degree of solubility of collagen increases with temperature and that at about 60°C collagen A shortens and is converted into collagen B (Lawrie, 1966). There were still uncoagulated water-soluble proteins, since 12.22 mg/g water-soluble material was obtained from the experimental samples of longissimus and only 6.45 mg/g was obtained from the well-done controls. The weight loss for this muscle was only 21.9% as compared with 38.7% for the well-done controls. It is reported that the combination of low pH and high temperature precipitates sarcoplasmic proteins on to the myofibril, lowering the water-holding capacity (Bendall et al., 1962).

Accordingly, reduced coagulation in this study resulted in juicier meat. During the subsequent holding period, further coagulation must have occurred, yet the amount of water-soluble material did not decrease nor did the meat express more juice. This does not preclude a shift in the location of the juice within the microstructure of the meat. The retention of the meat juice, together with the shrinkage of the collagen, may explain the increased tenderness of meat cooked for a long time at low temperatures.

Figure 5 shows the effect of heating temperature on the total weight losses for all muscles included in the study. All samples were heated at 0.1°C/min to the holding temperatures of 37, 45 and 60°C. The average of the control values is also shown. As the temperature increased, weight loss increased. Both the 37 and 45°C samples continued to lose weight after the holding period began. The 37°C samples lost weight at a constant rate throughout the entire holding period. The 45°C samples lost weight more rapidly during heating and the early part of the holding period, but little weight was lost after a total cooking time of 10 hr. The 60°C samples lost weight even more rapidly during the first 9 hr, but lost little during the last hour of cooking.

Marsh (1952a; 1952b) and Hamm (1956) concluded that the post-mortem increase in expressible water is accompanied by a tightening of fibrous structure and shrinkage of the tissue. Marsh (1962) has reported that shortening of muscle fibers during rigor mortis is directly proportional to temperature, up to 43°C. The effect of temperature on weight loss during cooking may be related to similar changes in meat structure.

From these studies, it would seem that the final temperature of the meat is extremely critical in affecting tenderness and weight loss. If the temperature is below the temperature at which collagen shrinks, the major decrease in tenderness does not occur. If the temperature is higher than the shrinkage temperature of collagen, the more severe coagulation will cause a higher weight loss and more tightly packed, less tender tissue will be formed. If the meat is heated to the collagen shrinkage temperature, there will be less weight loss, yet the major increase in tenderness will have occurred. If the meat is to be well done, it should be held at that temperature rather than heated further. Although not apparent from these data, the literature cited and the experiences of the authors indicate that slow heating may be essential if one is to

obtain the benefits of holding meat no hotter than 60°C.

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